Team Reports: SETI Institute

SETI Institute
Executive Summary
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The NASA Astrobiology Roadmap asks three fundamental questions: (1) How does life begin and evolve? (2) Does life exist elsewhere in the universe? and (3) What is the future of life on Earth and beyond? The SETI Institute NASA Astrobiology Institute (NAI) team is conducting a set of coupled research projects in the co−evolution of life and its planetary environment. These projects begin by examining certain fundamental ancient transitions that ultimately made complex life possible on Earth. They will conclude with a synthesis that will bring many of the team's investigations together into an examination of the suitability of planets orbiting M stars for either single−celled or more complex life.

The astrobiology roadmap calls for a strategy "for recognizing novel biosignatures" that "ultimately should accommodate a diversity of habitable conditions, biota and technologies in the universe that probably exceeds the diversity observed on Earth." Some of our results, especially those concerning abiotic mechanisms for the oxidation of planetary atmospheres, will speak to the interpretation of extrasolar planet atmospheric spectra (and in particular, the role of oxygen as a potential biosignature) in terms of the presence of photosynthesizing life. The team's M−star project addresses the roadmap's observation that "although technology is probably much more rare than life in the universe, its associated biosignatures perhaps enjoy a much higher signal−to−noise ratio. Accordingly, current methods should be further developed and novel methods should be identified for detecting electromagnetic radiation or other diagnostic artifacts that indicate remote technological civilizations." As the roadmap recognizes, there is a continuum of investigations that comprise astrobiology, from prebiotic evolution to the evolution of technology. We believe that we are the only NAI team whose investigations run the gamut of the roadmap's range.

The SETI Institute's NAI team's research emphasizes the elucidation of the co−evolution of life and its planetary environment, investigating global−scale processes that have shaped, and have been shaped by, both. Throughout, the team recognizes the importance of pursuing the planetary evolution aspects of this research in the context of comparative planetology: since laboratory experiments are impossible over many (but not all) of the time and spatial scales relevant to early Earth, we supplement laboratory data with insights gained by exploring extraterrestrial environments that provide partial analogs to the early Earth environment and its processes.

The SETI Institute team is pursuing two investigations into the oxidation of early Earth's environment. While the biological aspects of this "oxygen transition" have been emphasized, our team is exploring non–biological contributions to this transition. Dr. Friedemann Freund and Dr. Lynn Rothschild are investigating oxidation driven by diffusive loss of hydrogen formed within igneous and metamorphic rocks that incorporate water during crystallization. Subsequent weathering of the rocks released hydrogen peroxide into the environment; the previous loss of the hydrogen indicates that this is a net oxidizing mechanism. Experiments are underway (see Fig. 1 for preliminary results) to quantify the importance of this effect for a variety of powdered crystals; new data include the observation of oxygen evolution from finely powdered magnesium oxide crystals grown from melt.

In a second investigation, oxidation driven by atmospheric hydrocarbon (and, more broadly, organic) polymerization is being investigated by Dr. Emma Bakes. Dr. Bakes' research for the early Earth builds on analogies to processes now occurring in the atmosphere of Saturn's moon Titan. With her collaborators, Dr. Bakes is completing a comprehensive theory paper describing the chemical foundations of nitrogenated macromolecules in the Titan haze. This foundation enables the next stage of her research, the theoretical building of prebiotic macromolecules from the haze constituents. This work is complemented by ongoing laboratory work performed by Dr. Bishun Khare and Dr. Hiroshi Imanaka on Titan analog materials, and infrared observations of the Titan haze.

If the oxidation mechanisms being explored were shown to be quantitatively significant—modeling to be done later in the course of this grant—this would suggest that the oxygen transition on an Earth–like world could take place independently of the invention of any particular metabolic pathway (such as photosynthesis or methanogenesis) that have previously been proposed to drive this transition. Since Earth's oxygen transition ultimately set the stage for the oxygen–based metabolism evidently essential for metazoa, understanding this transition is crucial to elucidating both Earth's evolution and the evolution of complex (including intelligent) life. The team's geological investigations are therefore tightly coupled with microbiological experiments, led by Dr. Rothschild, to understand the extent to which the proposed mechanism might have led to the evolutionary invention of oxidant protective strategies and even aerobic metabolism.

Understanding the oxygen balance on early Earth requires attention to sinks as well as sources of oxygen. One major sink for oxygen on early Earth would have been reduced iron. Iron could have simultaneously provided shielding against ultraviolet (UV) light that would have been reaching Earth's surface in the absence of the ozone shield generated by atmospheric oxygen. Nanophase ferric oxide minerals in solution could provide a sunscreen against UV while allowing the transmission of visible light, in turn making the evolution of at least some photosynthetic organisms possible. Dr. Janice Bishop and Dr. Rothschild are testing this hypothesis through coupled mineralogical and microbiological work in both the lab and the field, and examining its implications not only for Earth but for Mars as well, with an emphasis on implications for upcoming spacecraft observations. UV, visible, and infrared spectra have been measured for a collection of iron−oxide−bearing samples, and experiments have been performed on cultures of two photosynthetic microorganisms, Euglena and Chlamydomonas, with and without iron species (see Fig. 2). The spectral data and growth patterns indicate that certain ferric oxide−bearing minerals could indeed have provided protection from UV radiation for early photosynthetic organisms, while still permitting the transmittance of the visible and infrared light required for photosynthesis. These results are consistent with the hypothesis that early photosynthetic organisms may have existed in specific, perhaps small, niches protected by ferric−oxide−bearing material.

The survival of microorganisms in very high UV environments can also be tested empirically through the exploration of Earth's highest altitude lakes and ponds, in Bolivia and Chile. Dr. Nathalie Cabrol and Dr. Edmond Grin (both of whom also this past year served on the Mars Exploration Rover team) have led a series of investigations of these lakes to examine the strategies employed by these microorganisms. The group they lead is currently analyzing samples and data from its 2003 expedition to Licancabur (6,014 m altitude) and lower lakes (Laguna Verde and Laguna Blanca, 4,430 m altitude), on the Bolivia/Chile boundary. Discoveries include an active community of modern stromatolites; the culture and phylogenetic characterization of apparently new bacterial species; and physical and chemical characterization of the lakes.

Just as global−scale changes in oxygen (or iron) were critical for the early biosphere, so too would have been global processes involving other key "biogenic" elements such as carbon (for which Dr. Bakes' work provides insight) or nitrogen. Dr. Rocco Mancinelli, Dr. Amos Banin, Dr. David Summers, and Dr. Khare are pursuing coupled laboratory and field research to understand the partitioning of nitrogen on early Earth and on Mars between different possible reservoirs, and (at least for Earth) the abiotic to biotic transition in this cycling.

Dr. Banin has begun the analysis of soil samples from the Atacama Desert, an extreme terrestrial environment with very low biological activity. In particular, it is as yet unclear what properties of the soil and environment are the limiting factors for biology, and the importance of nitrogen levels in this. Dr. Mancinelli and Dr. Banin have defined new field sites for their work in the Atacama that will begin this fall. Finally, they are experimentally investigating the possibility that binding of nitrogen as NH_4^+ in silicate minerals could account for the “missing” N on Mars, examining representative silicate minerals and Mars soil analogs and the biological availability of N when present in this form.

Dr. David Summers and Dr. Khare have begun their experimental work focusing on the demonstration of the abiotic fixation of nitrogen under the CO_2/N_2 atmosphere expected on early Mars. Nitrogen is theoretically predicted to be fixed via the production of NO via shock heating, followed by UV irradiation over liquid water. These experiments should provide a different perspective into the astrobiologically important question of the fate of N on early Mars.

The work described so far examines the evolution of planetary surface habitability. With the recognition that a subsurface ocean likely exists on Jupiter's moon Europa, we know that habitability in possibly entirely subsurface environments must also be explored. Dr. Cynthia Phillips, Dr. Christopher Chyba, and Mr. Kevin Hand (a Stanford PhD student advised by Dr. Chyba) are pursuing spacecraft data analysis and modeling to examine the geology of Europa and its implications for the free energy sources that would be needed to power a Europan biosphere. Dr. Phillips and Dr. Chyba are completing a major project, using Galileo high−resolution imaging of Europa, to quantify the impact cratering “gardening” rate on Europa. This is important in its own right as a fundamental planetary process, but also is important in some astrobiological models because it will allow the quantification of the amount of biologically relevant material, created at Europa's surface through radiogenic processes, that can be mixed down to the gardening depth, and thereby sequestered below the sputtering depth and significant radiolysis depth at the surface.

These results will be coupled with the results of low−temperature laboratory experiments to make predictions about the possible abundance and survivability of any oceanic biomarkers that might reach Europa's surface through active geology, with implications for the astrobiological exploration of Europa from either an orbiter or a surface lander. Mr. Kevin Hand, in collaboration with Dr. Robert Carlson and Dr. Chyba, is pursuing this research in Dr. Carlson's laboratory at the Jet Propulsion Laboratory. Over the past year, Mr. Hand and Dr. Carlson have constructed the irradiation apparatus (including ice deposition chamber and diagnostics) and have preliminary experiments now underway. Dr. Max Bernstein, in his laboratory at NASA Ames, has measured the mid−infrared spectra of several polycyclic aromatic nitrogen heterocycles in both neutral and cationic forms, and finds good agreement between theoretical prediction and experimental observation. Ultimately the behavior—and detectability—of such compounds under Europan conditions will also be determined.

Dr. Peter Backus, Dr. Jill Tarter, Dr. Mancinelli, and Dr. Chyba are beginning their examination of the prospects that planets orbiting dwarf M stars are habitable for either microscopic or complex life. The SETI Institute NAI team's proposal calls for a series of workshops to bring together planetary scientists, biologists, atmospheric modelers, astrophysicists, and SETI scientists to address these issues, to begin in year two of this proposal. Preliminary work so far includes a literature review, identification of workshop participants, and obtaining the full Tycho−2 star catalog and the database software that will be used to produce the list of M stars. The results of this project will ultimately help the next generation scientific Search for Extraterrestrial Intelligence (SETI) choose the million target stars (see the second figure) that it will survey for signs of technical civilizations using the new Allen Telescope Array (ATA), being built by the SETI Institute in partnership with the University of California, Berkeley.

Finally, education and public outreach are major and integral parts of the work of the SETI Institute's NAI team. They are addressed elsewhere in our first−year summary, so are not presented here.

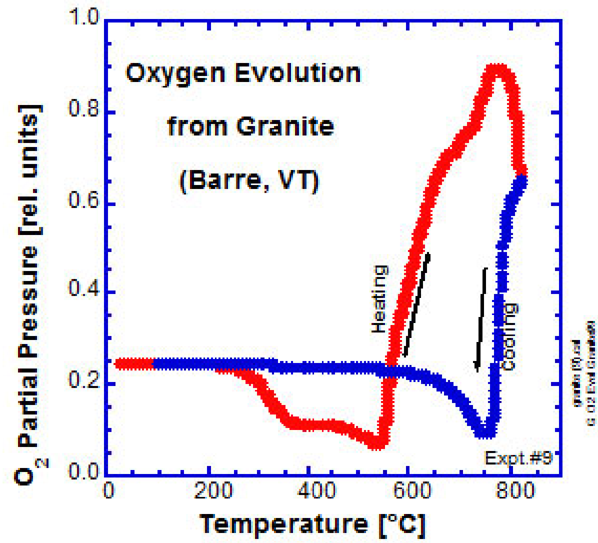

Fig. 1. Preliminary data showing O_2 evolution from crushed granite from the type location Barre , VT , during heating in a stream of N 2 with 100 ppm O_2 . Between 250–550 °C O_2 is consumed, but above 550 °C excess O_2 is released. The amount of O_2 gives an estimate of the average peroxy content in this rock of at least 500 ppm.

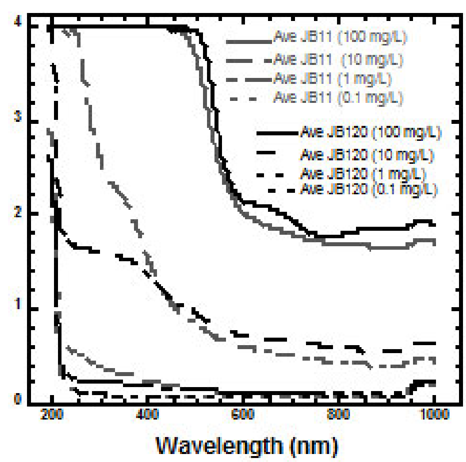

Fig. 2. Absorbance of Euglena and Chlamydonomonas in suspensions. The spectral absorbance due to chlorophyll in these organisms is clearly observed near 450 and 670 nm.